

# Mars-GRAM: Increasing the Precision of Sensitivity Studies at Large Optical Depths

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The Mars Global Reference Atmospheric Model (Mars-GRAM) is an engineering-level atmospheric model widely used for diverse mission applications. Mars-GRAM's perturbation modeling capability is commonly used, in a Monte-Carlo mode, to perform high fidelity engineering end-to-end simulations for entry, descent, and landing (EDL). It has been discovered during the Mars Science Laboratory (MSL) site selection process that Mars-GRAM, when used for sensitivity studies for MapYear=0 and large optical depth values such as  $\tau=3$ , is less than realistic. A comparison study between Mars atmospheric density estimates from Mars-GRAM and measurements by Mars Global Surveyor (MGS) has been undertaken for locations of varying latitudes,  $L_s$ , and LTST on Mars. The preliminary results from this study have validated the Thermal Emission Spectrometer (TES) limb data. From the surface to 80 km altitude, Mars-GRAM is based on the NASA Ames Mars General Circulation Model (MGCM). MGCM results that were used for Mars-GRAM with MapYear=0 were from a MGCM run with a fixed value of  $\tau=3$  for the entire year at all locations. This has resulted in an imprecise atmospheric density at all altitudes. To solve this pressure-density problem, density factor values were determined for  $\tau=.3$ , 1 and 3 that will adjust the input values of MGCM MapYear 0 pressure and density to achieve a better match of Mars-GRAM MapYear 0 with TES observations for MapYears 1 and 2 at comparable dust loading. The addition of these density factors to Mars-GRAM will improve the results of the sensitivity studies done for large optical depths.

## Nomenclature

<i>Mars-GRAM</i>	=	Mars Global Reference Atmospheric Model
<i>EDL</i>	=	entry, descent, and landing
<i>MSL</i>	=	Mars Science Laboratory
<i>TES</i>	=	Thermal Emission Spectrometer
<i>MGCM</i>	=	Mars General Circulation Model
<i>MGS</i>	=	Mars Global Surveyor
$L_s$	=	aerocentric longitude of Sun from Mars (degrees)
<i>LTST</i>	=	Local True Solar Time
$\tau$	=	Optical depth of background dust level
<i>MOLA</i>	=	Mars Orbiter Laser Altimeter

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## I. Introduction

It has been discovered during the Mars Science Laboratory (MSL) site selection process that the Mars Global Reference Atmospheric Model (Mars-GRAM) when used for sensitivity studies for Thermal Emission Spectrometer (TES) MapYear=0 and large optical depth values, such as  $\tau=3$ , is less than realistic. Mars-GRAM's perturbation modeling capability is commonly used, in a Monte-Carlo mode, to perform high fidelity engineering end-to-end simulations for entry, descent, and landing (EDL)<sup>1</sup>. Mars-GRAM 2005 has been validated<sup>2</sup> against Radio Science data, and both nadir and limb data from TES<sup>3</sup>.

Traditional Mars-GRAM options for representing the mean atmosphere along entry corridors include: TES mapping year 0, with user-controlled dust optical depth and Mars-GRAM data interpolated from NASA Ames Mars General Circulation Model (MGCM) model results driven by selected values of globally-uniform dust optical depth or TES mapping years 1 and 2, with Mars-GRAM data coming from (MGCM) results driven by observed TES dust optical depth. From the surface to 80 km altitude, Mars-GRAM is based on NASA Ames MGCM. Mars-GRAM and MGCM use surface topography from Mars Global Surveyor (MGS) Mars Orbiter Laser Altimeter (MOLA), with altitudes referenced to the MOLA areoid, or constant potential surface.

MGCM results that were used for Mars-GRAM with MapYear=0 were from a MGCM run with a fixed value of  $\tau=3$  for the entire year at all locations. This choice of data has led to discrepancies that have become apparent during recent sensitivity studies for MapYear=0 and large optical depths. Unrealistic energy absorption by uniform atmospheric dust leads to an unrealistic thermal energy balance on the polar caps. The outcome is an inaccurate cycle of condensation/sublimation of the polar caps and, as a consequence, an inaccurate cycle of total atmospheric mass and global-average surface pressure. Under an assumption of unchanged temperature profile and hydrostatic equilibrium, a given percentage change in surface pressure would produce a corresponding percentage change in density at all altitudes. Consequently, the final result of a change in surface pressure is an imprecise atmospheric density at all altitudes.

## II. Comparison Study between Mars-GRAM and MGS data

A comparison study between Mars atmospheric density estimates from Mars-GRAM and measurements by MGS has been undertaken for locations of varying latitudes,  $L_s$ , and LTST on Mars for both TES MapYear 1 and 2. TES MapYear 1 is from April 1999 through January 2001 a time during which the Mars was under normal atmospheric conditions. TES MapYear 2 is from February 2001 through December 2002 a period of time during which global dust storms occurred on Mars.

The list of locations studied on Mars is given in Table 1.

The ratios of TES Limb/Radio Science shown in Fig. 1 and TES Nadir/Radio Science shown in Fig. 2 illustrate how all the observed atmospheric density profiles compare to each other. As Fig. 1 and Fig. 2 show, the density ratios never varied by more than 0.04 from 1 and were always within 0.02 of each other. These results demonstrate that the observational profiles are consistent with each other and thus, validate the TES limb data.

$L_s$	30	45	60	75	90	105
Latitude	62	59	58	60	64	71
LTST	2	2	2	2	2	2

Table 1. Comparison Study Site Locations.

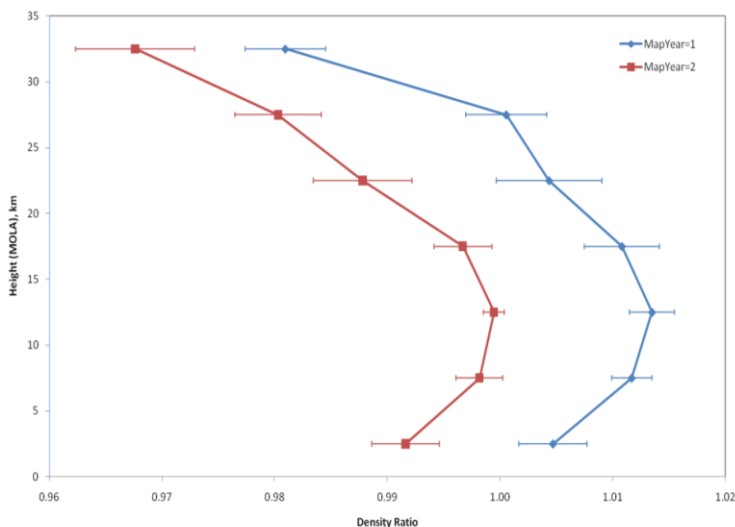
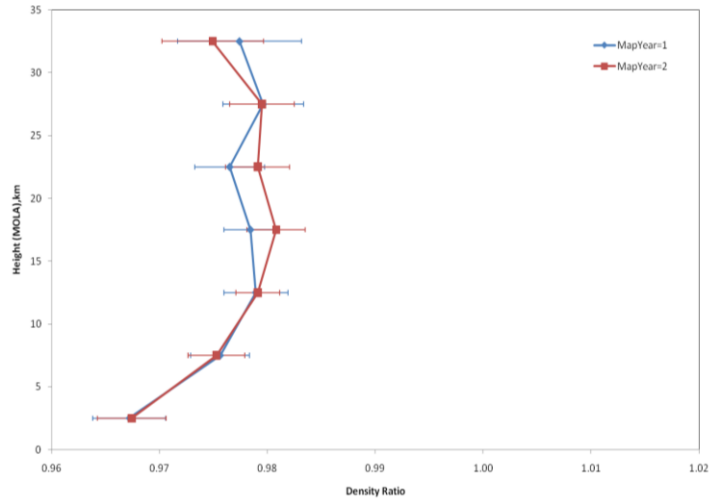


Figure 1. Atmospheric density comparison of ratios and standard deviations for TES Limb/Radio Science.

### III. Solving the Sensitivity Study Discrepancy for Large Optical Depths

In determining a possible solution to the discrepancy shown in the sensitivity study results for TES MapYear=0 and large optical depths, the TES Limb profiles were chosen for comparison because they extend to approximately 50 km. TES Radio Science and TES Nadir data extend only to approximately 35 km. The larger height range allows the Mars-GRAM and TES Limb profiles to be compared in the upper atmosphere.

The approach to solving this problem was derived by doing comparisons between Mars-GRAM Mapyear=0 and Mapyear=2 output. Mapyear=2 contains a large global dust storm, and so has a large number of  $\tau=3$  values. Separately, it was verified that Mars-GRAM Mapyear=2 output agreed fairly well with TES limb observations.



**Figure 2. Atmospheric density comparison of ratios and standard deviations for TES Nadir/Radio Science.**

### IV. Conclusions

A preliminary fix has been made to Mars-GRAM by adding a density factor value that was determined for  $\tau=0.3$ , 1 and 3. This factor adjusts the input values of MGCM MapYear 0 pressure and density to achieve a better match of Mars-GRAM MapYear 0 with MapYears 1 and 2 MGCM output at comparable dust loading. This factor multiplies the  $\tau=3$  densities and pressures by about 1.2, but leaves the  $\tau=0.3$  and 1.0 densities and pressures almost unchanged (multipliers near 1.0). These factors will automatically take care of intermediate  $\tau$  values between 1.0 and 3.0, since the  $\tau$ -interpolated values will have effective multipliers between 1.0 and 1.2. These updates can be found in Mars-GRAM 2005 Release 1.3.

Currently, these density factors are fixed values for all latitudes and Ls. Results will be presented from work being done to derive better multipliers by including variation with latitude and/or Ls by comparison of Mapyear=0 output directly against TES limb data. By comparing MapYear=0 output directly against TES limb data, better multipliers can be determined, including possible variation with latitude and/or Ls. Preliminary results for  $\tau=3$  have shown some latitude dependence. However, the  $\tau=3$  values occurred in the limb data only near Ls=210, so no Ls dependence could be determined for the high density cases. There are significantly more cases for  $\tau=1$  and  $\tau=0.3$  and will provide more information into the latitude and Ls variations. It is anticipated that these more accurate multipliers will be completed shortly and the results demonstrating the increased accuracy of Mars-GRAM Release 1.4 due to these new multipliers will be presented at the conference session.

### References

- <sup>1</sup>Striepe S. A. et al., "Mars Smart Lander Simulations for Entry, Descent, and Landing," AIAA Atmospheric Flight Mechanics Conference and Exhibit, 2002, Abstract # 2002-4412.
- <sup>2</sup>Justus C. G. et al., "Mars Aerocapture and Validation of Mars-GRAM with TES Data," 53rd JANNAF Propulsion Meeting, 2005.
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